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E-Mail: jar@y12.doe.gov Phone (865) 574-1306 Fax: (865) 574-7624
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IPP Greifswald officially opened

On 7 July 2000, the new buildings of the Greifswald branch of the Max-Planck-Institut für Plasmaphysik (IPP) were officially opened in the presence of German Chancellor Gerhard Schröder, Prime Minister of Mecklenburg-Vorpommern Harald Ringstorff, and numerous guests of honor. It was the first visit of Schröder to a town in Mecklenburg-Vorpommern, and IPP Greifswald was also the only one of 20 institutions in the new states to be opened by a head of government. The new buildings were finished on schedule and within budget after three years of construction. The employees were able to move to their new offices in April 2000 (see *Stellarator News* Issue 69). At this site, the fusion experiment Wendelstein 7-X is now being built — the biggest and most modern device of the stellarator type.

After a tour of the institute, Chancellor Schröder said that the federal government supports the Wendelstein 7-X project because—with regard to energy policy—nobody can afford not to explore possible routes to a safe energy supply for the future. At present, Wendelstein 7-X is one of the biggest German research projects supported by pub-

Fig. 1. The new IPP Greifswald building with its characteristic roof (Photo: Fetzi Baur).

Fig. 2. Chancellor Schröder during his tour of IPP Greifswald with Federal Minister of Education and Research Edelgard Bulmahn, President of the Max Planck Society Prof. Markl, Prime Minister Harald Ringstorff, and Prof. Wagner from Greifswald branch institute.

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Fig. 3. Chancellor Schröder and guests of honor in front of the Wendelstein 7-X mock-up.

lic funds and has an overall investment of 600 million deutschmarks.

With regard to the International Thermonuclear Experimental Reactor (ITER), Schröder said that the federal government reserves the right to carefully assess this project (investment of about 3.5 billion Euros) with the other European partners and to weigh the chances and risks of this new technology.

During the tour the EXPO 2000 project "Vision Fusion" was explained to the Chancellor, and the full-size mock-up of Wendelstein 7-X (Figs. 3 and 4) was shown to him. In June and July more than 2700 visitors seized the opportunity to visit the institute and to get information on fusion research in general and the importance of the energy question for the future.

The initiative of the Max Planck Society to found International Max Planck Research Schools was appreciated very much. These schools are to be established at exquisite places with excellent research and learning conditions to offer particularly qualified German and foreign students the opportunity to prepare for their Ph.D. examinations. Because of the cooperation of the Max Planck Institutes and neighboring universities Ph.D. students can make use of the training and research facilities of both partners. Such a Max Planck Research School is planned at IPP

Fig. 4. Full size mock-up of Wendelstein 7-X.

Greifswald, beginning this winter term. Additional opportunities for Ph.D. students will be provided by the Research School with its new course of study, "Plasma Technology and Fusion Research," at the University of Greifswald. The Greifswald Institute of Low Temperature Plasma Physics will also participate in the Research School.

Beate Kemnitz
Max-Planck-Institut für Plasmaphysik
Teilinstitut Greifswald
Wendelsteinstraße 1
17491 Greifswald, Germany

E-mail: beate.kemnitz@ipp.mpg.de

Infrared imaging video bolometer for LHD

Introduction

Research during the last five years at the National Institute for Fusion Science (NIFS) and Los Alamos National Laboratory has resulted in the development of imaging bolometers that use an infrared (IR) camera to detect the temperature rise of a metal foil exposed to plasma radiation and neutral particles [1–4]. A variation of this diagnostic known as the Infrared Imaging Video Bolometer (IRVB), which uses a single large foil mounted in a frame, was recently proposed [5]. This concept relies on a numerical method to solve for the diffusive contribution to the change in the foil temperature. A prototype of this diagnostic has been designed, installed on the Large Helical Device (LHD), and operated for the first time [6].

Design of the IRVB for LHD

The design of the LHD IRVB is shown in Fig. 1. The IRVB consists of a pinhole plate, a light-shielding tube, a foil-in-frame assembly, an IR vacuum window, a soft iron shield, and IR camera which are detailed below. The pinhole plate is made of 5-mm-thick stainless steel (SS) and the circular pinhole is beveled to a minimum diameter of 1 cm. The shielding tube is made of 1-mm-thick aluminum and has a light-tight vent located near the IR window to relieve air pressure differences between the inside and the outside of the tube during vacuum pumpdown. The vent hole is covered with two layers of electroformed grid to prevent microwaves from entering the tube and heating the foil or damaging the IR window [7]. The inside surfaces of the pinhole plate and light-shielding tube are blackened with graphite spray to prevent reflection of IR light.

The foil-in-frame assembly is shown in Fig. 2. The frame is made from two plates of 2-mm-thick oxygen-free copper. A $100 \times 100 \times 0.001$-mm gold foil is sandwiched between the frames, exposed on either side by holes in the frame pieces having the dimensions 66×90 mm. Bolts are used to tighten the frames together around the edge of the foil in order to ensure good contact between the gold foil and the frame. After assembly, the foil and frame are

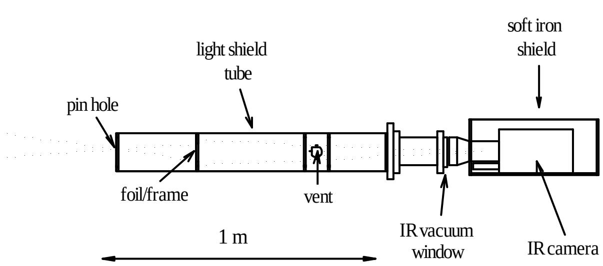

Fig. 1. Drawing of side view of LHD IRVB.

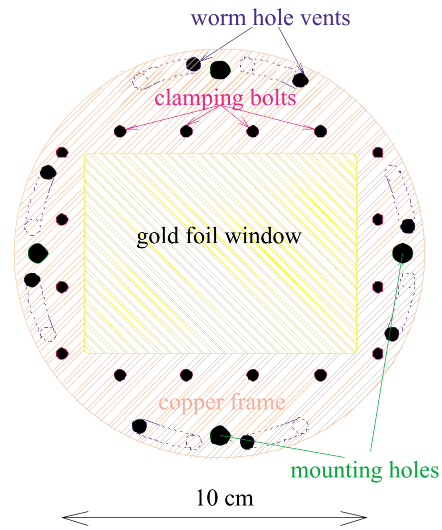

Fig. 2. Drawing of frame for foil of LHD IRVB.

blackened on the IR camera side with graphite spray in order to increase the IR emissivity. Using a groove and offset hole pattern cut into the frames, eight light-tight “wormhole” vents are formed around the periphery of the frame. These vents are intended to relieve any pressure differences which may arise between the two sides of the foil during vacuum pumpdown and up to air events.

The IR camera is an AGEMA THV 900 LW model with a scanning HgCdTe detector and a Stirling cooler. The wavelength range of the camera is 8–12 mm, the frame rate is 15 Hz for 136×272 pixels, and the nominal sensitivity is 80 mK at 30 C. The camera is equipped with a telephoto lens having a field of view of 5×10 degrees. A fiber-optic link is used to remotely operate the IR camera from the control room. Data from the camera can be acquired in 12-bit format and stored in a hard disk. A 6-mm-thick soft iron box shields the camera from magnetic fields which reach a maximum of 126 G at the camera location. While problems with operating this camera at an upper port because of strong magnetic fields have been reported elsewhere [4], we have not experienced any problems with the camera at the tangential port location of the IRVB, where the stray magnetic field is relatively small. The IRVB is installed at a tangential port located 21 cm below the midplane with a view of the plasma as shown in Fig. 3.

Data analysis technique, calibration, and noise equivalent power

In order to determine the incident radiated power density distribution on the foil, the technique described in Ref. 5 is used. Before applying this analysis several steps are taken. First, the IR images are compensated to eliminate the effects of reflections of nonthermal objects (such as the IR camera cooling element) and variations in the blackbody

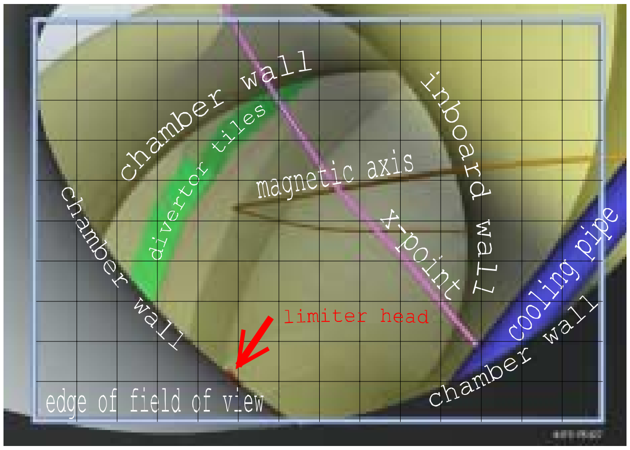

Fig. 3. Drawing of the field of view of the LHD IRVB from a tangential port.

emissivity of the foil and frame. This is done by subtracting a reference image taken before the discharge begins. Second, the images are reduced from 136 × 272 pixels to that portion of the image which contains the foil and part of the surrounding frame, which consists of 120 × 160 pixels. Next, the image is resampled using a linear interpolation technique to reduce the image to 12 × 16 bolometer pixels. This is the equivalent of averaging over 100 IR camera pixels for each bolometer pixel, which reduces the noise in the temperature measurement by a factor of 10. This image consists of a 1 bolometer pixel border viewing the frame and a 10 × 14 bolometer pixel view of the foil. Using these data the calculation of the incident radiated power distribution, $P_{rad}(x, y, t)$, given by Eq. (8) in Ref. 5 is made. This equation is derived using a solution to the two-dimensional heat diffusion equation to solve for the diffusion contribution to the temperature change of the foil and is rewritten below as

$$P_{rad}(x, y, t) = t_f k\{l^2([T(x, y, t) - T(x, y, t - \Delta t)]/\kappa\Delta t) \times [4T(x, y) - T(x, y + l) - T(x + l, y) - T(x - l, y)]_{t - \Delta t}\}, \quad (1)$$

where $l = 6.3$ mm is the dimension of the bolometer pixel, $t_f = 1\,\mu$m is the thickness of the foil, $\Delta t = 67$ ms is the time between IR camera frames (time resolution), κ is the effective thermal diffusivity of the foil, and k is the effective thermal conductivity of the foil. The effective thermal conductivity and the effective thermal diffusivity are determined through calibration with a 10-mW HeNe laser.

An expression for the noise equivalent power (NEP) for the IRVB derived as Eq. (21) in Ref. 5 is rewritten as the noise equivalent power density (NEPD) by dividing by the bolometer pixel area,

$$\eta_{IRVB}/l^2 = 2\sqrt{2}kt_f \frac{\sigma_{IR}}{l^2\sqrt{N_{IR}}}\left(\frac{1}{2}\frac{l^2}{\kappa\Delta t} + 1\right) , \quad (2)$$

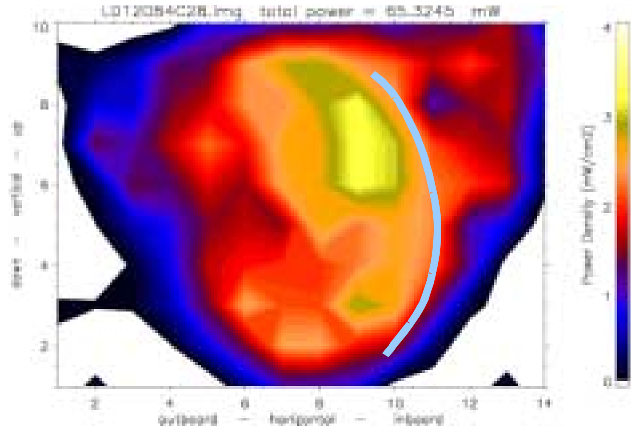

Fig. 4. Image from the IRVB during a discharge using the inboard wall as a limiter (blue line shows location of inboard wall).

where σ_{IR} is the IR camera temperature sensitivity and N_{IR} is the number of IR camera pixels making up one bolometer pixel. The nominal value of σ_{IR} is 80 mK; however, an actual value of 190 mK is measured, which is used for the NEPD calculation. When the values for k and κ determined from the calibration are included, an NEPD of 0.5 mW/cm^2 is obtained for this diagnostic when operated in 10 × 14 pixel mode at 15 Hz.

Measurements during the LHD experiment

In order to demonstrate the usefulness of this diagnostic, images taken from LHD discharges during the 1999 experimental campaign are shown in Figs. 4–7. The image in Fig. 4 comes from a series of discharges where the plasma was scraped off on the inboard vacuum vessel wall at the vertically elongated cross section of each field period by redistributing the helical coil currents to fatten the plasma in the plane bisecting the helical coils. This resulted in a radiation pattern that was localized near the inboard wall, as can be seen in the image from the IRVB in Fig. 4 and the image from the charge-coupled device (CCD) camera with a H_α filter in Fig. 5. The grid shown in Fig. 3 divides the view into pixels that correspond to the bolometer pixels indicated by the axes in Figs. 4 and 6. The CCD camera is located at the same port but on a flange that is slightly above and to the right of the IRV;, therefore, it has a slightly different view. The image shown in Fig. 6 was taken during a limiter insertion experiment. In Fig. 3 the limiter is faintly visible, shown in red in the lower left-hand edge of the bolometer's field of view. In Fig. 6 the image from the IRVB shows the radiation localized near the limiter. In Fig. 7 a similar picture is seen from the corresponding image from a CCD camera with a filter for CII. The limit of the field of view of the IRVB as determined by the vacuum vessel wall and other structural components is well defined in the images shown in Figs. 5 and 7 by a zero level for the power density.

Fig. 5. Image from a CCD camera with H_{α} filter corresponding to Fig. 4.

Discussion and plans

The best way to improve the sensitivity of the diagnostic would be to use a better IR camera. This means one with higher temperature sensitivity, more pixels, and a higher frame rate. As can be seen from the NEPD in Eq. (2), these factors would all lead to an improvement in the sensitivity. Another way to improve the signal-to-noise ratio would be to move the foil closer to the plasma to increase both its solid angle and the signal level. Moving closer to the plasma will complicate the diagnostic by requiring active cooling of the pinhole plate and light-shielding tube, especially during steady-state experiments.

We plan to install three imaging bolometers on LHD, all viewing the same plasma volume, in an attempt to use their signals to perform three-dimensional tomography of the plasma radiation.

B. J. Peterson, N. Ashikawa, M. Shoji, K. Nishimura
National Institute for Fusion Science, Toki, JAPAN
E-mail: peterson@LHD.nifs.ac.jp

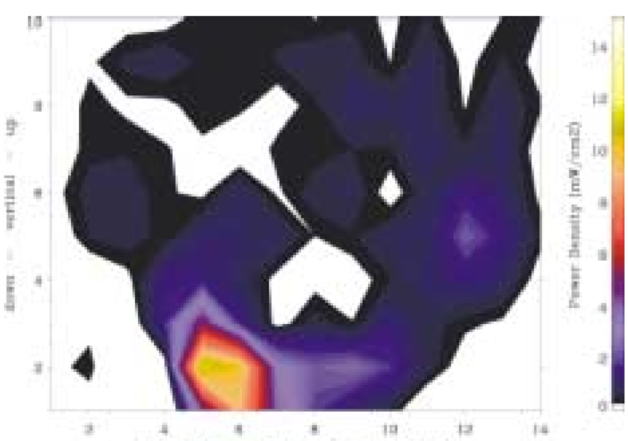

Fig. 6. Image from the IRVB during a discharge using an insertable limiter.

Fig. 7. Image from a CCD camera with CII filter corresponding to Fig. 6.

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